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A COMPARISON OF THE FATIGUE BEHAVIOR OF HIGH STRENGTH CAST ALUMINUM ALLOYS 201 AND A357

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Northrop Corporation
Hawthorne, California

1 December 1971

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Northrop Corporation
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NOR 71-229

A COMPARISON OF THE FATIGUE BEHAVIOR OF HIGH STRENGTH CAST ALUMINUM ALLOYS 201 AND A357

1 December 1971

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REVISIONS

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ABSTRACT

The notched fatigue strength of high strength aluminum casting alloys A357 and 201 was evaluated using separately cast round tensile bar coupons. These results are considered satisfactory for comparison purposes of the alloys, but should not be used for design criteria.

The results are plotted in the form of S/N curves representing the behavior of the materials under conditions of repeated axial loading of tension-tension and tension-compression. The results show a close similarity of behavior of the materials.

The materials are also compared by ultimately failing the surviving fatigue specimens in tension and then by comparing microstructures of the test specimens exhibiting highest and lowest ultimate tensile strengths. The notched tensile strength of 201 was higher than A357; notched strength values of 201 specimens were reduced by partial eutectic melting and undissolved eutectic in grain boundry regions.

ACKNOWLEDGMENT

The author wishes to acknowledge the efforts of D. C. Atmur and his co-workers of the Northrop Structural Laboratories who performed the fatigue tests and Messrs L. Stone, D. Rosas, W. Smith, and F. Flower of the Northrop Materials Laboratories for their efforts in preparing the photomicrographs and tensile property data. The material tested was provided by the Electronic Specialty Company, Foundry Division, Pomona, California, who the author is indebted to for their kind assistance and cooperation in the test program. The fatigue test data shown in Appendix 1 was extracted from Northrop Internal Report NOR-69-107, dated 31 July 1969.

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INTRODUCTION

Structural aircraft materials are required to meet minimum tensile properties to satisfy anticipated stress requirements of the finished part. However, in addition to the tensile properties requirements, fatigue characteristics are, in some instances, of equal or greater importance to the performance of the part. Published axial fatigue data representing repeated loading in tension and repeated alternate loading of tension and compression is generally very limited for high strength aluminum casting alloys.

OBJECTIVE

The objective of the investigation was to determine the notched fatigue strength of high strength aluminum casting alloy 201 in both the T6 and T7 heat treat conditions and alloy A357 in the T6 heat treat condition.

CONCLUSION

Notched fatigue behavior of unchilled test bars of A357-T6, 201-T6, and 201-T7 alloys are similar when exposed to alternate axial loading of tension-tension or tension-compression.

TEST MATERIAL

Test bars were randomly selected of each alloy and heat treat condition to determine the tensile strength of the various test materials. The results are shown in Table 1. The elongation values were somewhat lower than normally obtained in premium quality castings of these alloys because chills are not used in the test bar molds. The test bars were all cast in green sand molds and rigged in the manner shown in Figure 1. Production castings are normally cast in sand molds with metal chills stratigically located for directional solidification of the casting and better mechanical properties.

The alloy chemistry for each melt of material was within the composition limits of Tables 2 and 3. Heat treat procedures employed were as follows:

Alloy 201

1. Solution Treatment

Held at 970 F for 2 hours then raised temperature to 985 F and held for 20 hours followed by quench in room temperature water.

2. Aging Treatment

For T6 Condition: Soaked at 310 F for 20 hours.
For T7 Condition: Soaked at 370 F for 5 hours.

Alloy A357-T6

1. Solution Treatment

Held at 1000 F for 2 hours then raised temperature to 1020 F and held for 16 hours then quenched in room temperature water.

2. Aging Treatment

Soaked at 330 F for 5 hours.

TEST PROCEDURE

Fatigue specimens conforming to the configuration shown in Figure 2 were machined from the reduced section of separately cast round tensile test specimens described in Figure 3.

The fatigue testing was performed in 3 test machines. A Baldwin SF-4 was used primarily for the 201-T6 specimens; a Baldwin IV-20 was used primarily for 201-T7 specimens; and a IV-20 was used primarily for the A357-T6 specimens. The material was tested at 2 stress ratios, R = -1.0 and R = +0.2. To obtain a stress ratio of R = -1.0, the specimen was subjected to a tension-compression load cycle of equal magnitude in tension and compression. For a stress ratio of R = +0.2, the specimen was subjected to tension-tension load cycling between a maximum and minimum stress of which the magnitude of the minimum stress is 20 percent that of the maximum stress.

A total number of 88 201-T6, 89 201-T7, and 47 A357-T6 fatigue specimens were tested. Nine 201-T7, 15 201-T6, and 11 A357-T6 notched fatigue specimens that did not fail in test were pulled to failure in tension. Metallographic comparisons were made of the 201 specimens exhibiting the highest and lowest tensile strength.

TEST RESULTS AND DISCUSSION

Figures 4A and 4B show the S/N fatigue curves plotted from the test results of the 201 and A357 test specimens. The test results are shown in the appendix. The results indicated a similarity of notched fatigue properties of the A357 and 201 alloys and a similarity of notched fatigue properties of T6 and T7 heat treat conditions of 201 alloy. These tests were performed to evaluate the relative fatigue characteristics of the alloys and do not represent production castings, therefore, the results should not be used for design criteria. It is speculated that production castings of finer grain size produced in alloy 201 or smaller dendritic arm spacing in alloy A357 would exhibit higher fatigue properties.

The ultimate tensile strength of the notched fatigue specimens which did not fail in fatigue was determined and these results are shown in Table 4. The relative higher notch toughness of the 201 alloy in both the T6 and T7 heat treat conditions compared to A357-T6 alloy specimens was evident.

The microstructures of specimens exhibiting the highest and lowest notched tensile strength were examined. These microstructures are shown in Figures 5A, 5B, 6A, 6B, 7A, and 7B. The following microstructural observations were made:

201-T6 - Undissolved eutectic in the grain boundary of the microstructure reduced the notched tensile strength of the material.

201-T7 - Partial eutectic melting in the grain boundaries of the microstructure reduced the notched tensile strength of the material.

A357-T6 - Very little discernable difference was found in the lower and higher strength specimens.

TABLE 1. TENSILE PROPERTIES OF TEST MATERIAL

Test Material	Tensile Properties		
	Ultimate Strength, ksi	Yield Strength at 0.2 Percent Offset, ksi	Elongation in 1 inch, percent
A357-T6	51.7	44.1	4.5
	49.9	42.8	4.5
	51.3	45.0	5.5
Average	51.0	44.0	4.8
201-T6	67.7	56.9	10.5
	66.3	56.7	7.0
	68.9	59.7	7.0
	67.3	55.7	10.0
	67.9	59.7	7.0
	69.4	61.7	7.0
Average	67.9	58.4	3.1
201-T7	65.8	62.5	4.0
	66.0	63.1	2.0
	65.3	62.6	2.0
Average	65.7	62.7	2.7

TABLE 2. ALUMINUM ALLOY 201 CHEMICAL COMPOSITION LIMITS

Element	Percent	
	Minimum	Maximum
Copper	4.0	5.0
Silver	0.4	1.0
Magnesium	0.18	0.35
Manganese	0.20	0.30
Titanium	0.15	0.35
Iron	--	0.10
Silicon	--	0.05
Others, Each	--	0.03
Others, Total	--	0.10
Aluminum	Remainder	Remainder

TABLE 3. ALUMINUM ALLOY A357
CHEMICAL COMPOSITION LIMITS

Element	Percent	
	Minimum	Maximum
Silicon	6.5	7.5
Magnesium	0.40	0.75
Titanium	0.10	0.20
Beryllium	0.04	0.25
Copper	--	0.20
Iron	--	0.20
Manganese	--	0.10
Zinc	--	0.10
Others, Each	--	0.05
Others, Total	--	0.15
Aluminum	Remainder	Remainder

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TABLE 4. TENSILE STRENGTH OF NOTCHED SPECIMENS NOT FAILING IN FATIGUE

Alloy	Specimen	Notched Tensile Strength, ksi	Ratio of Notched Tensile Strength to Tensile Strength
201-T6	7	97.1	
	10	92.6	
	26	96.6	
	4	97.1	
	5	95.7	
	15	76.1	
	19	98.1	
	60	104.1	
	61	100.3	
	63	106.6	
	65	98.6	
	66	103.7	
	67	105.2	
	68	107.5	
	80	108.1	
	Average	99.2	1.46
201-T7	9	84.9	
	11	87.6	
	13	88.4	
	38	85.6	
	55	82.0	
	56	81.7	
	65	93.5	
	89	94.4	
	92	77.2	
	Average	87.2	1.33
A357-T6	7	66.1	
	24	68.8	
	25	62.7	
	30	64.0	
	32	65.5	
	33	66.2	
	34	66.1	
	35	65.4	
	41	64.3	
	44	65.1	
	45	59.6	
	Average	64.9	1.27

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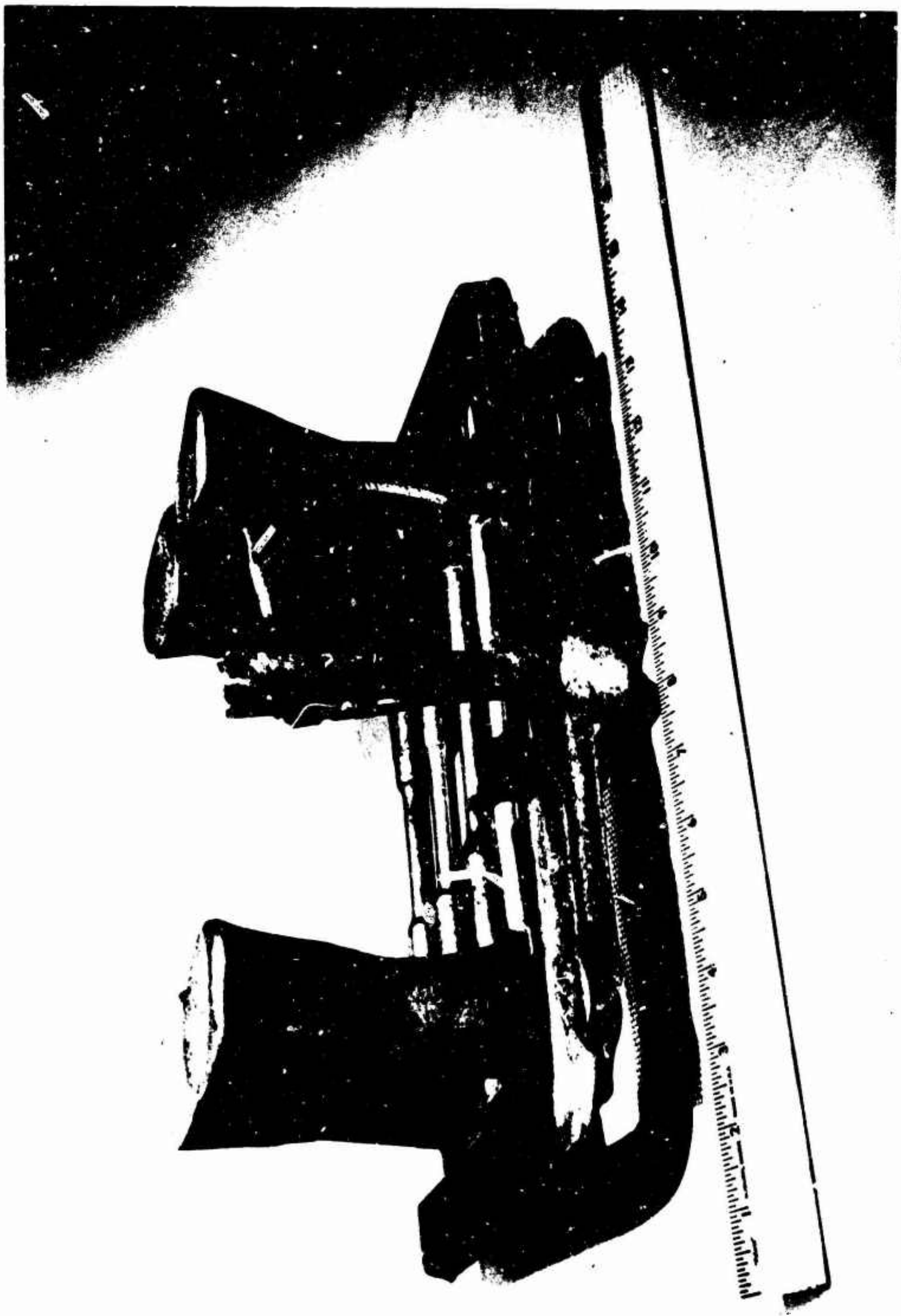

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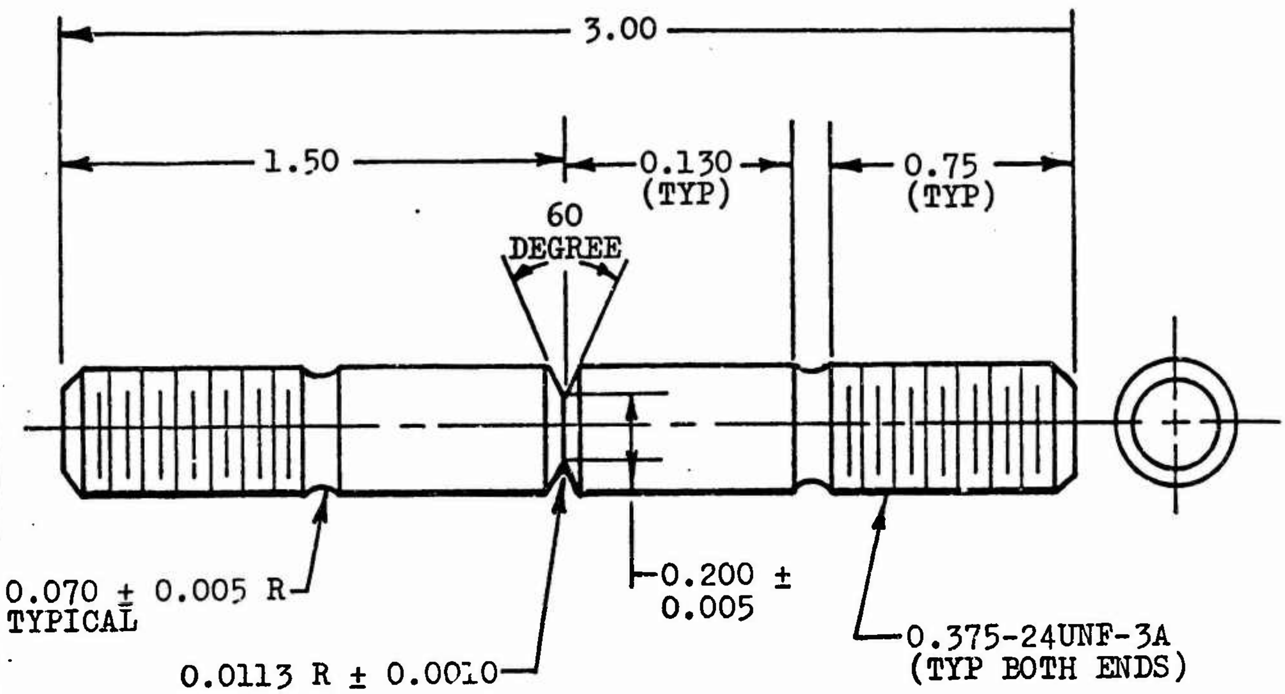
FIGURE 1. CAST TEST BARS WITH RIGGING



STRESS CONCENTRATION $K_t = 3.4$

NOTE: ALL DIAMETERS CONCENTRIC WITHIN 0.001

FIGURE 2. FATIGUE SPECIMEN CONFIGURATION

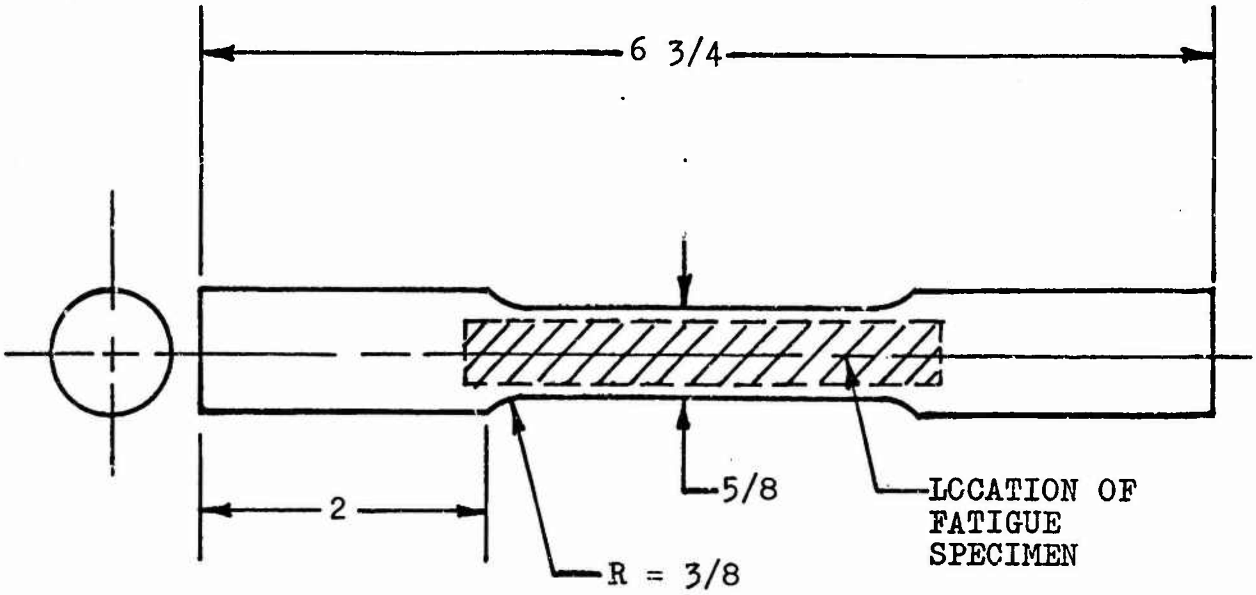


FIGURE 3. CAST TEST BAR CONFIGURATION

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FIGURE 4A. TENSION-TENSION NOTCHED AXIAL FATIGUE TEST RESULTS
(AVERAGE VALUES PLOTTED)

TENSION-TENSION (R = 0.2) $K_t = 3.4$ ROUND SEPERATELY CAST TEST BARS (UNCHILLED) REF: NOR 69-107

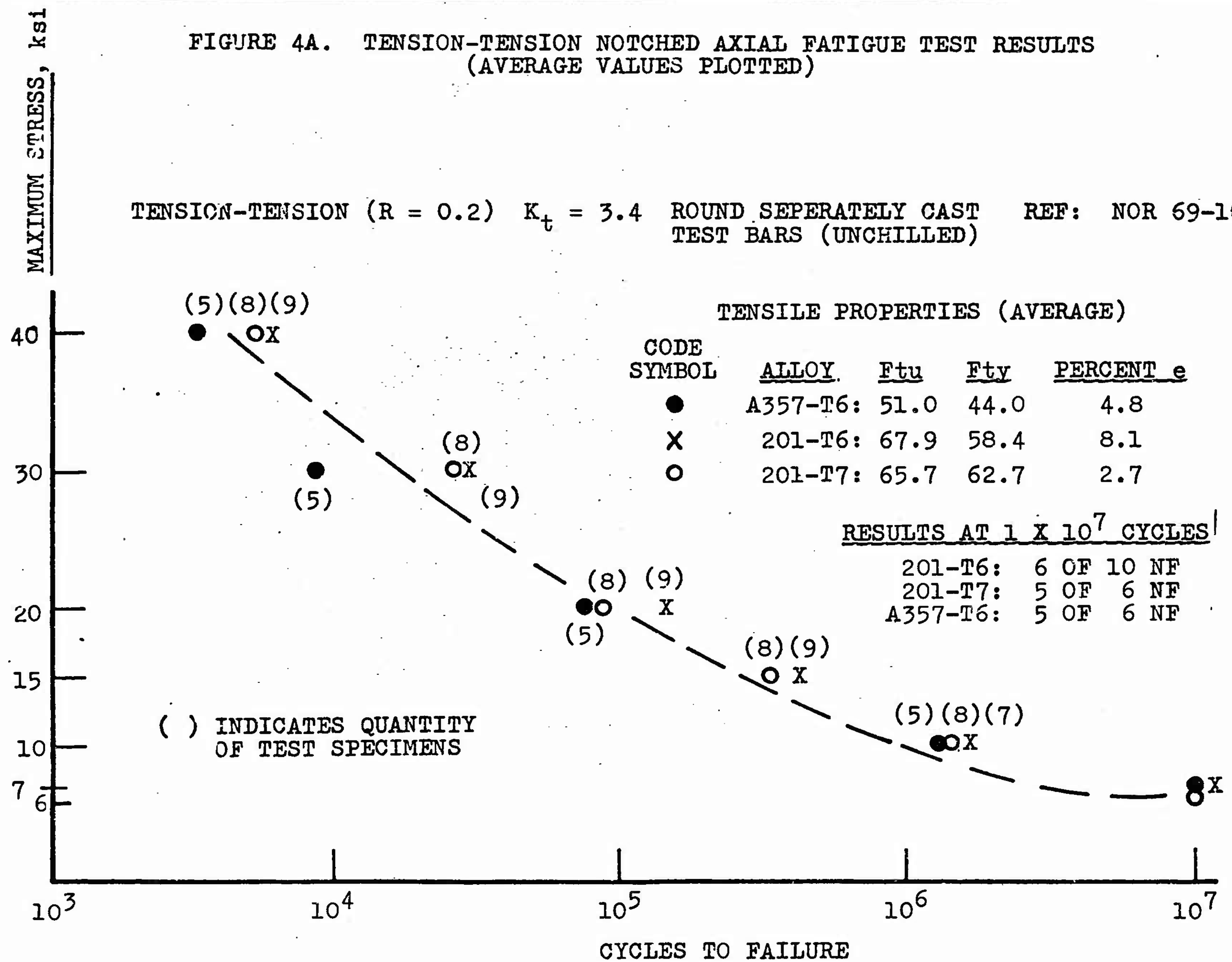

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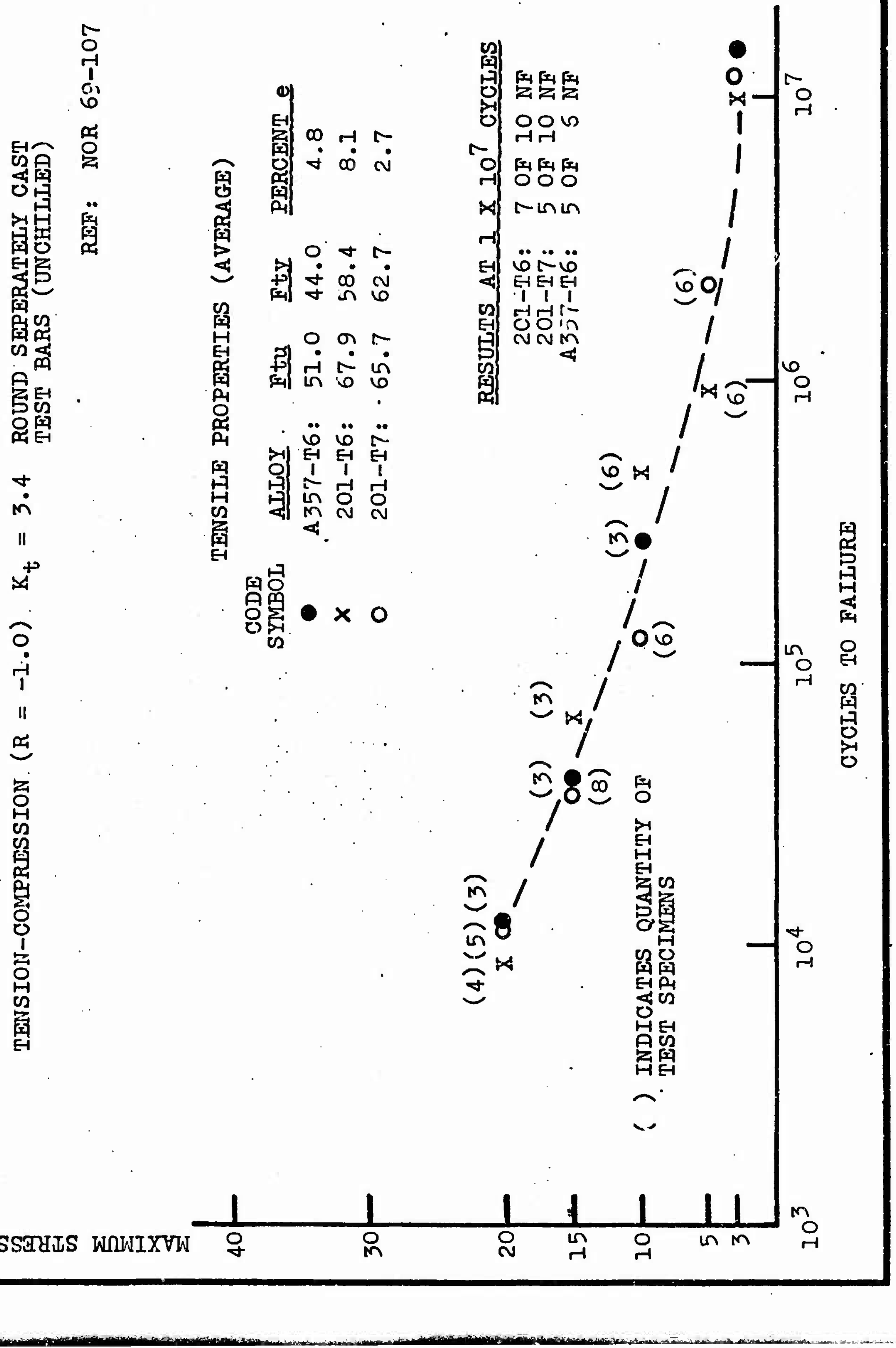
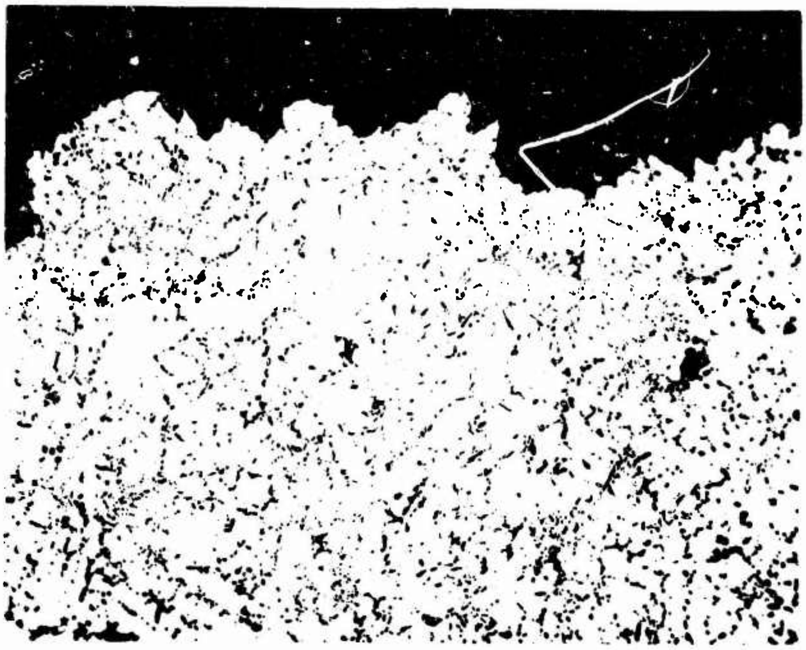
FIGURE 4B. TENSION-COMPRESSION NOTCHED AXIAL FATIGUE TEST RESULTS (AVERAGE VALUES PLOTTED)





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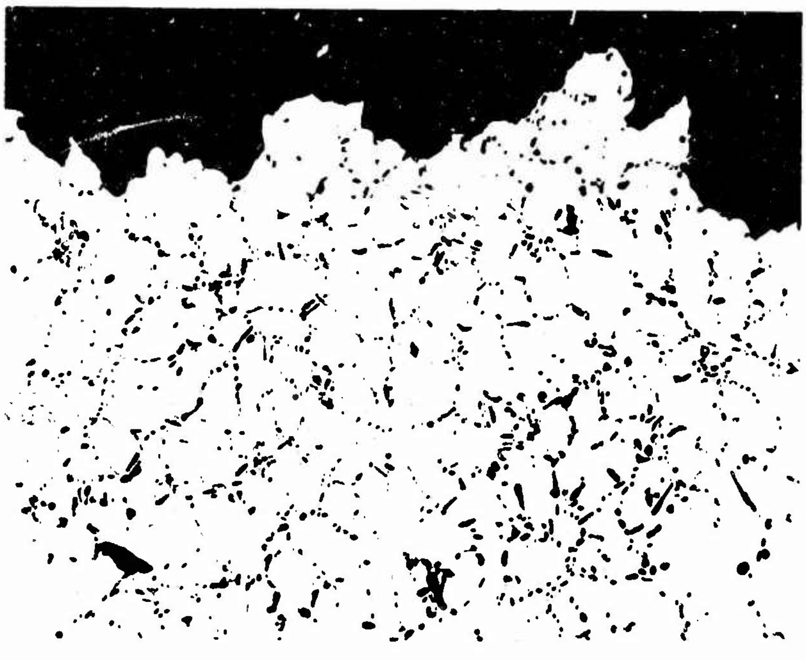

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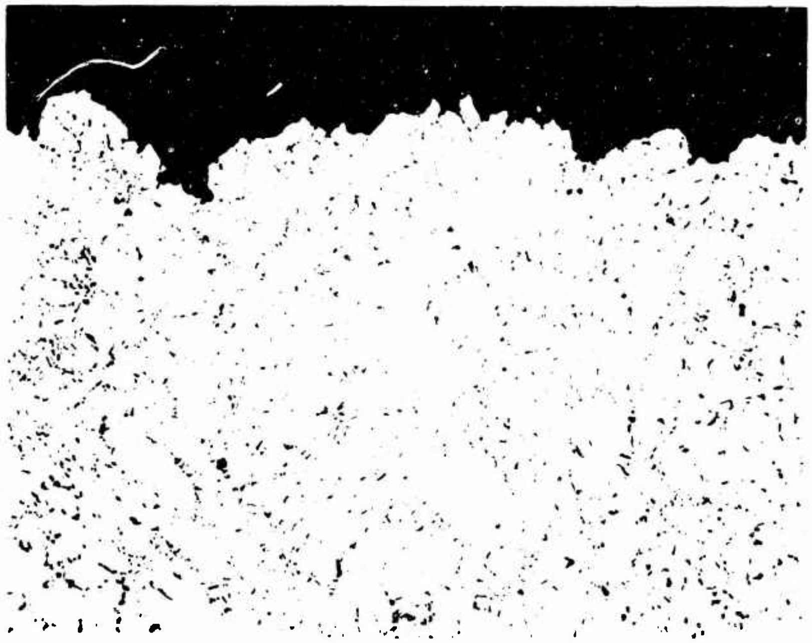
FIGURE 5A. TYPICAL MICROSTRUCTURE AT FRACTURE OF A357-T6
SPECIMEN WHICH FAILED IN TENSION AT 59.6 KSI
(LOWEST VALUE OF SPECIMENS TESTED)



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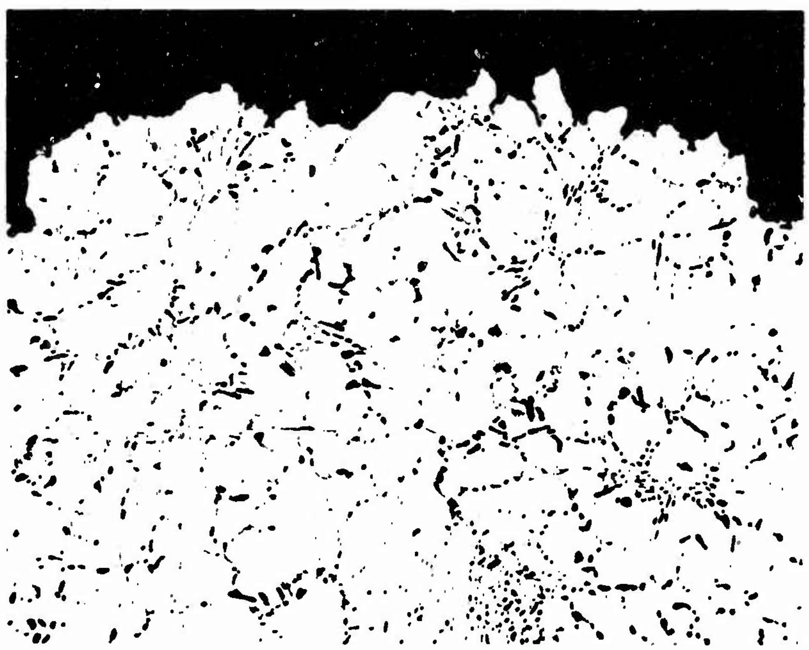

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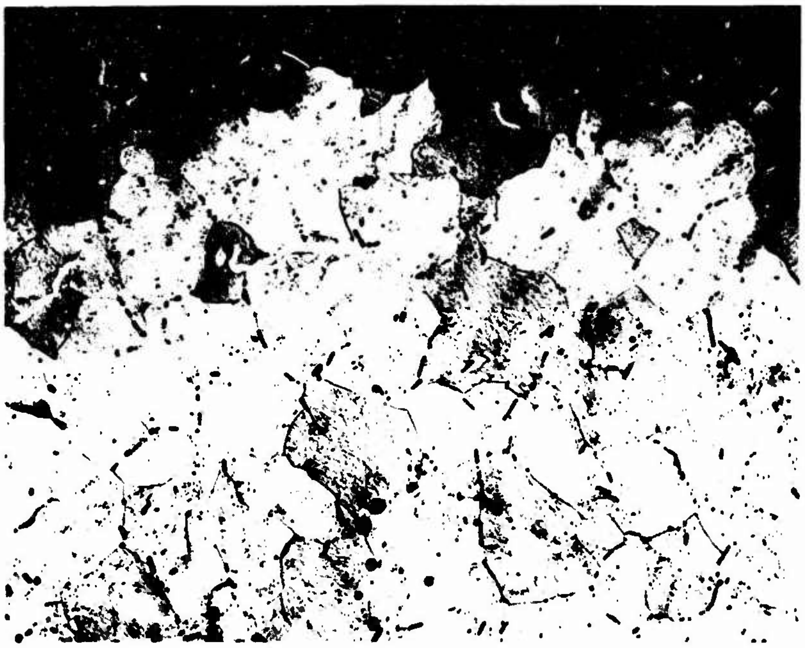
FIGURE 5B. TYPICAL MICROSTRUCTURE AT FRACTURE OF A357-T6 SPECIMEN FAILED IN TENSION AT 68.8 KSI (HIGHEST VALUE OF SPECIMENS TESTED)



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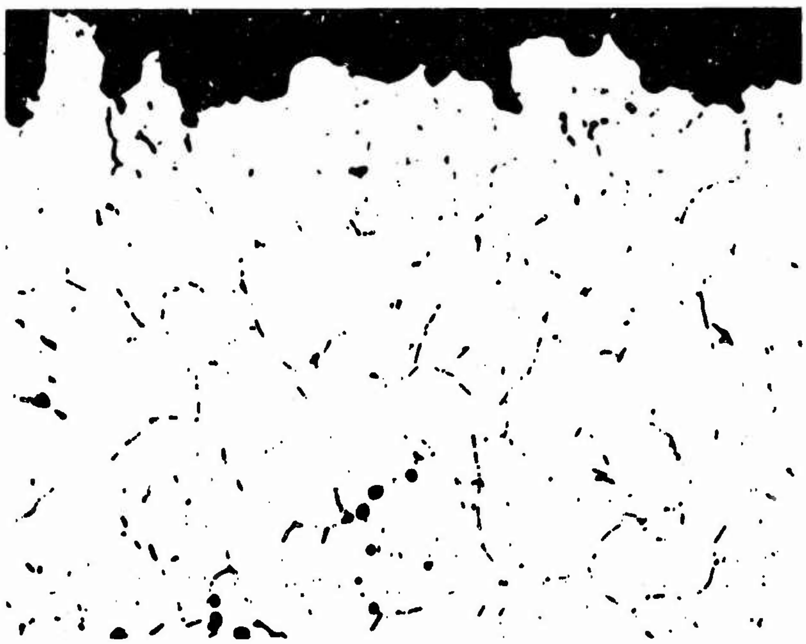

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FIGURE 6A. TYPICAL MICROSTRUCTURE AT FRACTURE OF 201-T6 SPECIMEN FAILED IN TENSION AT 76.1 KSI (LOWEST VALUE OF SPECIMENS TESTED)

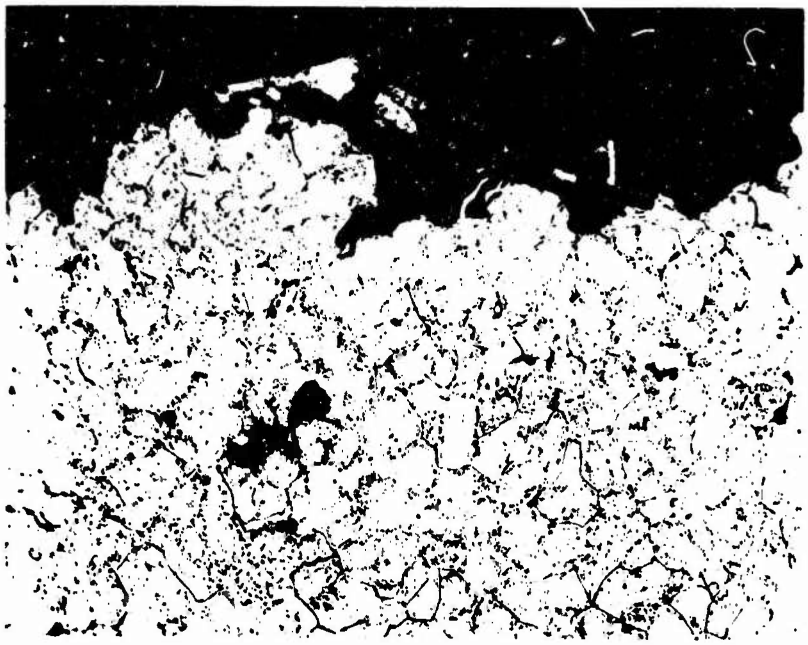

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FIGURE 6B. TYPICAL MICROSTRUCTURE AT FRACTURE OF 201-T6 SPECIMEN FAILED IN TENSION AT 108.1 KSI (HIGHEST VALUE OF SPECIMENS TESTED)

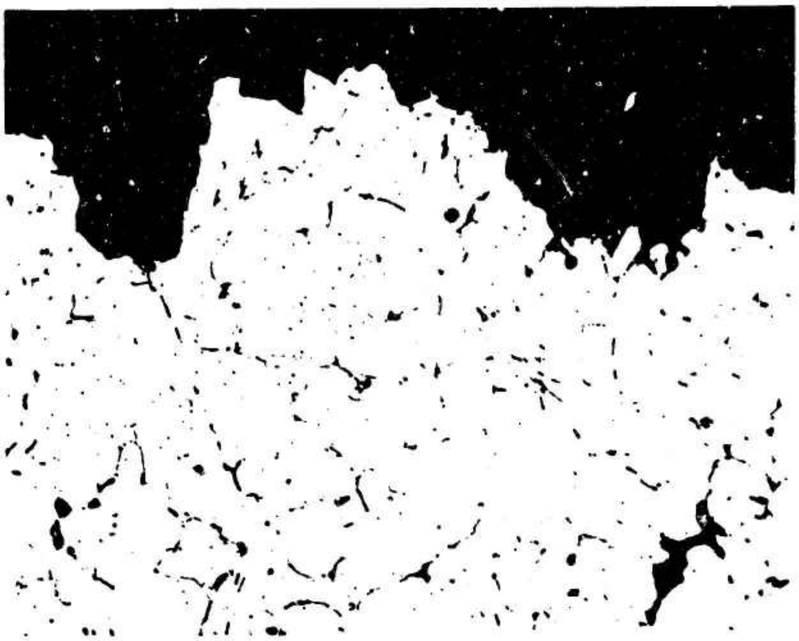

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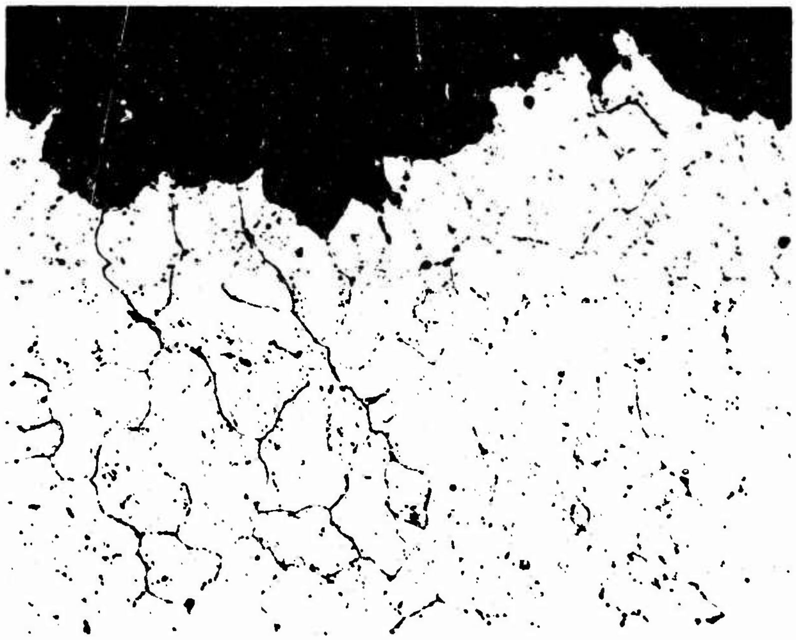
FIGURE 7A. TYPICAL MICROSTRUCTURE AT FRACTURE OF 201-T7 SPECIMEN FAILED IN TENSION AT 77.2 KSI (LOWEST VALUE OF SPECIMENS TESTED)



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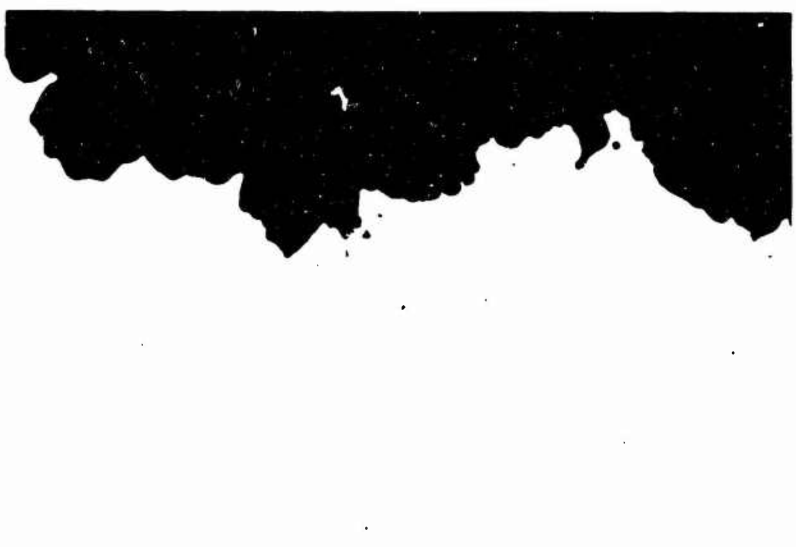

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FIGURE 7B. TYPICAL MICROSTRUCTURE AT FRACTURE OF 201-T7
SPECIMEN FAILED IN TENSION AT 94.4 KSI
(HIGHEST VALUE OF SPECIMENS TESTED)

APPENDIX 1

FATIGUE TEST DATA

(ORIGINALLY REPORTED IN NORTHROP INTERNAL REPORT NOR 69-107 BY D. C. ATMUR, 31 July 1969)

TABLE A1. ALUMINUM ALLOY 201-T6, FATIGUE
CYCLES TO FAILURE AT R = 0.20

Specimen No.	Maximum Stress, psi	Cycles to Failure
4-6	40,000	6,000
4-15		5,000
4-24		7,000
4-25		5,000
4-14		10,000
T6-92		10,000
T6-87		7,000
T6-91		6,000
T6-82	40,000	7,000
4-12	30,000	19,000
4-18		32,000
4-27		28,000
T6-86		34,000
T6-81		26,000
T6-85		30,000
T6-90		31,000
T6-83		34,000
T6-84	30,000	28,000
5-23	20,000	185,000
4-19		236,000
4-17		191,000
4-16		161,000
4-2		139,000
T6-88		125,000
T6-87		124,000
T6-79		61,000
5-1	20,000	85,000
4-23	15,000	536,000
5-16		346,000
5-13		391,000
4-8		568,000
4-22		218,000
4-9		344,000
4-1		254,000
T6-94		326,000
5-18	15,000	686,000

TABLE A1. (CONTINUED)

Specimen No.	Maximum Stress, psi	Cycles to Failure
T6-83	10,000	890,000
5-10		1,779,000
5-11		2,591,000
5-12		1,701,000
5-14		1,948,000
5-7		1,793,000
5-21		1,822,000
5-22		2,062,000
T6-80	10,000	10,434,000*
4-21	8,000	3,482,000
4-28	8,000	2,313,000
5-19	7,500	10,218,000*
5-20	7,500	3,991,000
5-17	7,500	6,107,000
4-10	7,000	11,612,000*
4-7		10,296,000*
4-26		10,117,000*
5-9		6,993,000
5-5		10,319,000*
5-4		11,526,000*
5-15		10,577,000*
5-2		5,096,000
5-6		8,870,000
5-3	7,000	4,208,000

* No failure.

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TABLE A2. ALUMINUM ALLOY 201-T6, FATIGUE CYCLES TO FAILURE AT R = -1.0

Specimen No.	Maximum Stress, psi	Cycles to Failure
T6-50	20,000	9,000
T6-51		11,000
T6-52		6,000
T6-69	20,000	9,000
T6-76	15,000	66,500
T6-77	15,000	81,000
T6-78	15,000	34,000
T6-70	10,000	224,000
T6-53		740,000
T6-54		145,000
T6-55		1,560,000
T6-72	10,000	116,000
T6-73	5,000	612,000
T6-74		683,000
T6-56		1,581,000
T6-57		678,000
T6-58		705,000
T6-75	5,000	1,301,000
T6-59	3,000	6,759,000
T6-60		10,175,000*
T6-61		10,331,000*
T6-62		7,405,000
T6-63		10,210,000*
T6-64		6,867,000
T6-65		12,081,000*
T6-66		10,353,000*
T6-67		10,437,000*
T6-68	3,000	10,022,000*

* No failure.

TABLE A3. ALUMINUM ALLOY 201-T7, FATIGUE CYCLES TO FAILURE AT R = 0.20

Specimen No.	Maximum Stress, psi	Cycles to Failure
T7-21	40,000	4,000
T7-22		6,000
T7-23		4,500
T7-24		7,000
T7-25		5,000
T7-88		4,000
T7-95		8,500
T7-97	40,000	8,000
T7-16	30,000	16,000
T7-18		22,000
T7-20		45,000
T7-85		12,000
T7-78		9,000
T7-83		6,000
T7-79		12,000
T7-90	30,000	8,000
T7-1	20,000	93,500
T7-2		77,000
T7-3		76,000
T7-26		112,000
T7-27		62,000
T7-82		49,000
T7-86		86,000
T7-80	20,000	39,000
T7-33	15,000	200,000
T7-34		329,000
T7-35		575,000
T7-15		214,000
T7-17		167,000
T7-19		451,000
T7-36	15,000	357,000
T7-4	10,000	1,052,000
T7-5		753,000
T7-28		1,681,000
T7-29		984,000
T7-30		923,000
T7-31		977,500
T7-32	10,000	961,000

TABLE A3. (CONTINUED)

Specimen No.	Maximum Stress, psi	Cycles to Failure
T7-6	8,000	1,123,000
T7-7		1,566,000
T7-14		1,876,000
T7-12	8,000	1,509,000
T7-48	7,500	2,968,000
T7-38	7,500	10,493,000*
T7-39	7,500	3,261,000
T7-41	7,000	1,433,000
T7-42	7,000	1,444,000
T7-43	7,000	2,123,000
T7-8	6,000	11,181,000*
T7-9		10,310,000*
T7-11		10,775,000*
T7-13		10,254,000*
T7-91		5,699,000
T7-84		9,134,000
T7-92	6,000	10,152,000*

* No failure.

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TABLE A4. ALUMINUM ALLOY 201-T6, FATIGUE CYCLES TO FAILURE AT R = -1.0

Specimen No.	Maximum Stress, psi	Cycles to Failure
T7-40	20,000	6,000
T7-44		12,000
T7-45		7,000
T7-57		15,000
T7-59	20,000	19,000
T7-96	15,000	73,000
T7-73		12,000
T7-37		71,000
T7-75		28,000
T7-76		23,000
T7-77	15,000	60,000
T7-68	10,000	26,000
T7-46		74,000
T7-47		125,000
T7-50		357,000
T7-60		76,000
T7-71	10,000	16[illegible],000
T7-61	5,000	3[illegible],000
T7-62		831,000
T7-51		1,011,000
T7-52		4,000,000
T7-53		5,440,000
T7-63	5,000	495,000
T7-64	3,000	2,916,000
T7-54		931,000
T7-55		12,806,000*
T7-56		10,280,000*
T7-65		12,957,000*
T7-66		2,476,000
T7-67		1,383,000
T7-58		10,038,000*
T7-69		10,270,000*
T7-70	3,000	4,891,000

* No failure.

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TABLE A5. ALUMINUM ALLOY A357-T6, FATIGUE CYCLES TO FAILURE AT R = 0.20

Specimen No.	Maximum Stress, psi	Cycles to Failure
3-10	40,000	3,000
3-11		3,500
3-12		3,200
3-38	40,000	3,500
3-13	30,000	7,000
3-14		4,000
3-15		9,500
3-43		9,500
3-47	30,000	14,000
3-16	20,000	47,000
3-17		147,000
3-28		59,000
3-22		66,000
3-23	20,000	41,000
3-19	10,000	620,000
3-20		1,082,000
3-21		878,000
3-36		3,022,000
3-48	10,000	863,000
3-37	8,000	1,767,000
3-46	8,000	1,883,000
3-24	7,000	10,220,000*
3-25		10,029,000*
3-45		10,279,000*
3-42		2,932,000
3-44		10,338,000*
3-33	7,000	10,000,000*

* No failure.

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TABLE A6. ALUMINUM ALLOY A357-T6, FATIGUE CYCLES TO FAILURE AT R = -1.0

Specimen No.	Maximum Stress, psi	Cycles to Failure
3-1	20,000	6,000
3-2	20,000	11,000
3-4	20,000	19,000
3-27	15,000	37,000
3-18	15,000	13,000
3-29	15,000	71,000
3-3	10,000	200,000
3-5	10,000	445,000
3-6	10,000	169,000
3-7	5,000	10,320,000*
3-8		2,499,000
3-9		576,000
3-40		2,299,000
3-34	5,000	12,848,000*
3-30	3,000	10,900,000*
3-31		6,344,000
3-32		10,133,000*
3-41		10,241,000*
3-35		10,345,000*
3-39	3,000	10,000,000*

* No failure.